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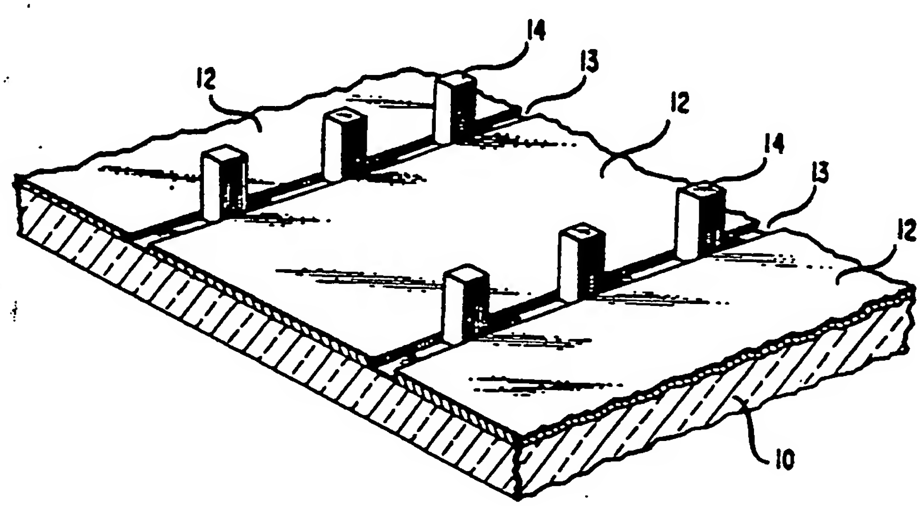
(54) Title: THIN, UNIFORM ELECTRO-OPTIC DISPLAY

(57) Abstract

A liquid crystal display in which the cell has a uniform thickness of the order of 1 μm. The uniform thickness of the cell is controlled by means of an array of pillars (14) located between the electrodes on the glass back plate (10). The pillars comprise a material (e.g., polyimide) which adheres to both plates, thus reducing the tendency of the plates to bow.



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THIN, UNIFORM ELECTRO-OPTIC DISPLAY

Background of the Invention

This invention relates to displays utilizing an electro-optic material and, more particularly, to such displays which include thin cells of uniform thickness. although the invention is described primarily in conjunction with a liquid crystal (LC) cell, which represents its chief intended application, it will be appreciated that it can be used to advantage with display cells employing alternative electro-optic materials, specifically cells based on electropheretic or electrochromic liquids.

In a liquid crystal display (LCD) the LC cell includes a pair of glass plates which are sealed around their periphery to form a thin chamber which contains the LC material. Transparent electrodes are formed on the interior surfaces of the plates to control the molecular orientation of the LC material in response to an electric field induced by voltage applied to the electrodes. Changing the orientation of the LC molecules changes the transmission of light through the cell. By applying voltage to selected ones of the electrodes, patterned displays are produced.

The thickness of an LC cell, which is defined as the distance between the glass plates, has a significant impact on its operation. For example, bistable ferroelectric LCDs recently proposed by N. A. Clark et al, Applied Physics Letters, Vol. 36, page 899 (1980), require a cell thickness of approximately 1 μm in order for the helix of the molecules to be unwound and, thus, for bistability to be present. On the other hand, conventional twisted nematic LCDs, which are used in calculators and computers, are about 5.5 to 12 μm thick and consequently have turn-off times in the range of about 50 to 100 ms. However, a thickness of 2μm, if attainable, would reduce the turn-off time to about 5 ms.

In the common commercial arrangement, the thickness of a cell is determined by the diameter of thin, glass fibers which are uniformly scattered over the entire surface of one of the plates before assembling the cell. See, U.S. Patent 4,283,119 granted to H. Hoffman on August 11, 1981. Presently, however, the minimum diameter of the fiber spacers is about 5.5 μm, thus limiting the best turn-off time to about 50 ms. An earlier arrangement, which has not received commercial acceptance because of its complexity, is proposed by A. M. Leupp et al in U.S. Patent 3,978,580 on September 7, 1976. A spacer lattice having a cell-like structure is formed on the back plate, with the walls of the lattice lying between the electrodes. The walls include an insulative base (e.g., an oxide), which rises above the electrodes, and a metal top portion (e.g., aluminum). The heights of the composite walls, which are uniform relative to the back plate, enable cell thicknesses of 5.5 to 9.5 μm to be achieved. Alternatively, Leupp et al propose a spacer wall made of a single insulative material such as polysilicon.

In addition to thickness per se, the uniformity of the cell thickness over the area of the plates is also important. As pointed out by Leupp et al, bowing of the front plate, which tends to be thinner than the back plate, causes uneven electric fields to be applied across the width and length of the cell, thereby producing uneven changes in the appearance of the LC material across the display.

While the fiber spacers of Hofmann and the spacer lattice of Leupp et al establish a uniform minimum thickness of the cell, thus being an effective deterent to inward bowing of the front plate, neither patentee teaches achieving uniformity against outward bowing. In addition, neither describes a practical, simple process for attaining extremely thin cells of the order of 1 μm thick.

Summary of the Invention

We have found that thin, uniform cells suitable

for use in electro-optic displays, particularly LCDs, can be realized by incorporating an array of pillars between the front and back plates. The pillars are formed from a thin film of material which possesses the following characteristics: (1) it can be patterned (e.g., by photolithography) to leave an array of pillars on one plate (e.g., the back plate); (2) it can be deposited uniformly on the one plate to the desired thickness (e.g., 1-2μm); and, importantly, (3) it can be made to form an adhesive bond to both plates. With the pillars adhering to both plates, bowing (especially outward bowing) is significantly reduced.

Brief Description of the Drawing

Our invention, together with its various features and advantages, can be readily understood from the following more detailed description taken in conjunction with the accompanying drawing, in which the figures are not drawn to scale in the interest of clarity.

FIG. 1 is an isometric view of the back plate of an LCD in accordance with one embodiment of our invention;

FIG. 2 is a cross-sectional view of the front plate and back plate, just prior to assembly, in accordance with the embodiment of FIG. 1; and

FIG. 3 is a cross-sectional view of an assembled LC cell in accordance with the embodiment of FIGS. 1 and 2.

Detailed Description

With reference now to FIG. 1, there is shown the back plate 10 of an LCD. A plurality of transparent electrodes 12 are formed on back plate 10 and, in accordance with one aspect of our invention, an array of pillars 14 is formed in the channels 13 between the electrodes 12. Although not shown, the pillars may overlap the edges of the electrodes, but this configuration is not critical. As shown in FIG. 2, an alignment layer 16 is deposited over the electrodes and the pillars. Likewise, the front plate 20 of FIG. 2 generally includes a plurality

of transparent electrodes 22 on its interior surface. The arrangement, orientation and shape of the electrodes depend on the particular application. Sealing means 24 is preferably disposed around the periphery of front plate 20. When assembled as shown in FIG. 3, the sealing means 24 bonds the front and back plates together, thus forming a thin chamber for containing liquid crystal material 30. Importantly, the thickness of the cell is controlled and made uniform by the array of pillars 14 which extend between the plates 10 and 20. The pillars, as discussed hereinafter, are formed from a material which adheres to the plates 10 and 20, thereby reducing the tendency of the plates to bow, particularly the front plate 20 which is typically thinner than the back plate 10. In addition, in order to establish the desired thickness of the cell the pillars are made to have uniform height.

As mentioned previously, a significant aspect of our invention resides in the ability to fabricate thin LC cells of uniform thickness. In conventional twisted nematic LCDs, thin cells imply low turn-off times, and certain ferroelectric LCDs require that the thickness of the cell be in the range of 1 μm for materials such as 4-n-decycloxybenzilidene-4'-amino(2-methyl-butyl) cinnamate (DOBAMBC) and 4-n-decycloxybenzilidine-4'-amino(2-chloropropyl) cinnamate (HOBAPC) described by N. A. Clark, <u>supra</u>.

The two desiderata, thin and uniform cells, are satisfied simultaneously by the use of a thin film, preferably a polyimide, which possesses the following properties:

(1) the film can be patterned, for example, by photolithography;

(2) the film can be deposited to a uniform, desired thickness; and

(3) the film is capable of forming an adhesive bond to both the front and back plates.

Patterning of the film enables an array of pillars

to be formed in the desired regions of the display. Uniform deposition enables the pillars to have essentially the same height over the entire display area so that spacing uniformity between the two glass plates is achieved. Whereas the minimum cell thickness is determined by the pillar height, the maximum thickness is controlled by the adhesion of the pillars to both plates, thereby ensuring that the thickness of the cell corresponds to the thickness of the pillars.

Example

The following example describes a ferroelectric LCD in which an array of polyimide pillars was used to fabricate a cell having a uniform thickness of about 2μm. Materials, dimensions and other parameters are provided by way of illustration only and, unless otherwise stated, are not to be construed as limitations on the scope of the invention.

The thin film used to form the pillars was a polyimide sold under the trademark of PYRALIN by E. I. Dupont Co. While the choice of PYRALIN may not be optimum, it nevertheless has the above-mentioned three properties.

Each plate (10, 20) was patterned with sixty indium-tin-oxide (ITO) electrodes 12 which were 1.143 mm wide, separated by 0.127 mm channels 13 and several hundred Angstroms thick. The pillars 14 were located in the channesl 13 between the electrodes. They were arranged in a square array and were separated by about 1.27 mm. The geometry of the pillars was chosen to be a square parallelepiped measuring 0.127 mm square and about 0.002 mm high. Other pillar shapes are, however, suitable. The alignment coating 16 was typically 300 Angstroms thick and was deposited using the techniques and materials described in the copending application of J. W. Goodby et al, Case 3-3-1, Serial No. 518,640 filed on July 29, 1983 and assigned to the assignee hereof. The glass back plate 10 was typically 1.52 mm thick, and the glass front plate 20 was 0.762 mm. (Similar cells where the front and back plates

were both 1.52 mm were also fabricated successfully.) The height of the seal 24 before assembly was typically 0.01 mm. Although a smaller seal height, comparable to the height of the pillars, is desirable, practical limitations of the screening procedure makes this difficult.

The size of the square cross-section of the pillars is dictated by the number of pillars, the strength of the cohesive bond between the pillars and the plates, and the force required to keep flat the initially warped plates. The cohesive strength of polyimide bonded to glass was determined from a tension stress test to be approximately 1600 psi. The maximum deformation which occurs midway between the pillars is given approximately by

$$Y_{max} = \frac{0.046PL^4}{Yd^3}$$

where Y is Young's modulus of glass (which is of the order of 10^{-7} psi), P is the uniform pressure acting on the uniform flat plate, d is the thickness of the plate and L is the pillar spacing. This equation can also be used to estimate the pressure required to flatten a warped piece of glass assuming uniform loading. In order to flatten a 0.060 inch of thick glass plate used in our experiments, approximately 14 psi of uniform pressure is required. Taking into account the cohesive strength of the polyimide bond to the glass plate, this result indicates that the pillars should occupy one tenth of the surface area in order to prevent the glass plate from bending back into its original shape after bonding. The spacing between the pillars, therefore, would be determined by the size of the pillars, assuming a fixed surface area. While the cross-

section of the pillars should be as small as possible in order to reduce the likelihood that they will be seen, there are practical considerations that limit the smallest size. In particular, the size is a function of photolithography mask resolution and the undercutting that occurs during the developing step. With our presently available equipment, a pillar size as small as about 25 μm square can be realized. However, smaller dimensions may be possible with higher resolution equipment and/or processing. For a given cross-sectional size of the pillars, fewer would be required if a thinner glass front plate is used, since, as is evident from equation (1), it is easier to deform thinner glass.

An illustrative fabrication procedure for the above cell includes the following principal steps.

An ITO conductive coating was first deposited on the glass plates. This step included depositing about 600 Angstroms of indium-tin metal by DC of magnetron sputtering in a commercially available station with a power of about 0.7 KW at a pressure of 5 millitorr in a 25% oxygen/argon atmosphere. The oxidation of the indium-tin coating was achieved by heating at 300°C for an hour followed by a vacuum bake at 300°C for an hour at 30 millitorr.

The ITO electrodes were patterned using Shipley 1300-15 photoresist and etched in an aqueous mixture of 50% HCl and 3% HNO_3 at 55°C. After etching, photoresist covering the electrodes was removed using Shipley 1112A solution, and the plates were cleaned in detergent in concentrated H_2SO_4 containing ammonium persulphate before washing in deionized water.

PYRALIN 2566 was sprayed using a commercially available in-line conveyer coating system. For a 2 μm coating a 4.7% solids solution of polyimide in 75% ethyl cellesolve plus 25% N-methyl pyrrolidone was used.

After the coating had dried and cooled off, it was overlaid with photoresist. The desired pattern of pillars was obtained by conventional photolithographic techniques.

Shipley MF-312 was used both as a developer and a polyimide etchant. Photoresist covering the unexposed regions was removed using butyl acetate.

Finally, an aligning coating of a polyester material was applied to the plates by spinning deposition of about 300 Angstroms of poly(1,4-butyleneterephthallate) using a 0.5% solution in 50% 1,1,2,2 tetrachloroethane and 50% o-chlorophenol. The plates were spun at about 4000 R.P.M. for 30 seconds and then baked at 120°C for 30 minutes.

An edge seal material, ABLEBOND 681-14, which is a trademark of Ablestik Laboratories, Gardena, California, was applied to the front plate using a well-known silk screening procedure. The screen had a 7.5 μm thick emulsion pattern which defined the area to be covered with the sealing material. The screen was a 248 mesh. After depositing the seal material, the plates were prebaked at about 100°C for about one half hour.

Both of the plates were buffed to promote alignment of the liquid crystal molecules in the direction of buffing. For a ferroelectric LC, however, buffing only one plate may be adequate. The plates were then assembled with the buffing directions parallel to one another and placed in a fixture capable of producing pressure in excess of about 20 psi. Sealing was accomplished by passing the fixture through a commercially available furnace. The temperature-time profile for sealing was as follows: 25°C-100°C for 35 min., 100°C-150°C for 30 min., 150°C-200°C for 30 min., 200°C-150°C for 15 min., and finally 150°C-100°C for 15 min.

At this point the cell was filled with a ferroelectric LC using standard vacuum filling techniques.

While the cells produced using the above-mentioned procedure were uniform, care was required in maintaining the glass plates dust free. Two cells were fabricated by the procedure outlined above, but for purposes of comparison the polyimide pillars of one cell were pre-baked

before sealing using the time-temperature profile above. Because pre-baking prevents the pillars from bonding to the front plate, photomicrographs showed that the pre-baked cell had a high degree of thickness nonuniformity. This test confirmed the importance of pillar-to-plate adhesion in achieving uniform cells.

Inasmuch as the sheet glass used for plates 10 and 20 intrinsically has greater variation in thickness as the average glass thickness decreases, the polyimide pillars are preferably deposited on the thicker glass plate (usually the back plate 10) if the plates 10 and 20 are of unequal thicknesses. An added advantage of this approach is that the thinner plate is easier to deform and thus requires less force to prevent it from bending to its original shape.

It is important not to seal the cells under excessive pressure since this makes the cell thickness much less than the height of pillars prior to sealing. Under normal pressure (about 20 psi), the ratio of the final cell thickness to the height of the pillars prior to sealing is about 0.8. This ratio changes as a function of the time-temperature sealing profile.

In particular, while the foregoing example demonstrates the fabrication of a cell having a uniform thickness of about 2 μm, even thinner cells (e.g., 1 μm or less) are possible by using a thinner polyimide layer. In addition, the example utilized an aligning layer deposited on top of the pillars and electrodes. However, the aligning layer can also be deposited on top of the electrodes and back plate before forming the pillars.

Claims:

1. An electro-optic display characterized by

a cell having a pair of transparent plates forming a chamber for containing an electro-optic material, at least one of said plates having a tendency to bow, and

an array of pillars of uniform height located between said plates, said pillars comprising a material which adheres to both of said plates thereby reducing the tendency of said at least one plate to bow.

2. The display of claim 1 characterized in that the material of said pillars comprises polyimide.

3. The display of claim 2, characterized in that the electro-optic material comprises a liquid crystal.

4. The display of claim 3, characterized in that the liquid crystal comprises a ferroelectric material.

5. The display in accordance with any of claims 1-4, characterized in that the pillars have a uniform height on the order of 1 μm.

6. The display in accordance with any of claims 1-4, characterized by further including transparent, spaced-apart electrodes formed on said interior surface of at least one of said plates, and wherein the pillars are formed on at least one plate in the spaces between the electrodes.

7. A liquid crystal display characterized by

a transparent glass front plate,

a transparent glass back plate,

transparent electrodes formed on the interior surfaces of each of said plates, the electrodes on at least one of said plates being separated from one another by channels therebetween,

means sealing said plates to one another along the periphery thereof, thereby forming between said plates a chamber for containing a liquid crystal material, and

an array of polyimide pillars located in said channels, said pillars extending between and adhering to both of said plates.

8. The display of claim 7, further including an

aligning layer formed over said electrodes.

9. The display of claim 7, characterized in that the pillars have a uniform height on the order of 1 μm.

10. The display of claim 9 characterized in that the liquid crystal comprises a ferroelectric material.

11. A method of fabricating a liquid crystal display comprising,

providing a transparent glass back plate and a transparent glass front plate,

depositing a transparent conductor material on a major surface of each of said plates,

patterning said conductive material to form electrodes, said electrodes on at least said back plates being spaced from one another by channels therebetween,

depositing a layer of polyimide on said back plate over said electrodes and said channels

patterning said polyimide to form in said channels an array of pillars of uniform height,

after said patterning step and before said sealing step, depositing an aligning layer on said electrodes on said back plate,

sealing said top plate to said bottom plate around the periphery of said plates so that said top plate contacts the top of said pillars,

curing said polyimide pillars to cause them to adhere to said top plate, and

introducing a liquid crystal material into the space between said plates.

12. The method of claim 11 characterized in that the polyimide layer is deposited to a thickness of the order of 1μm.

13. The method of claim 11 or 12 characterized in that the liquid crystal material is ferroelectric.

FIG. 1

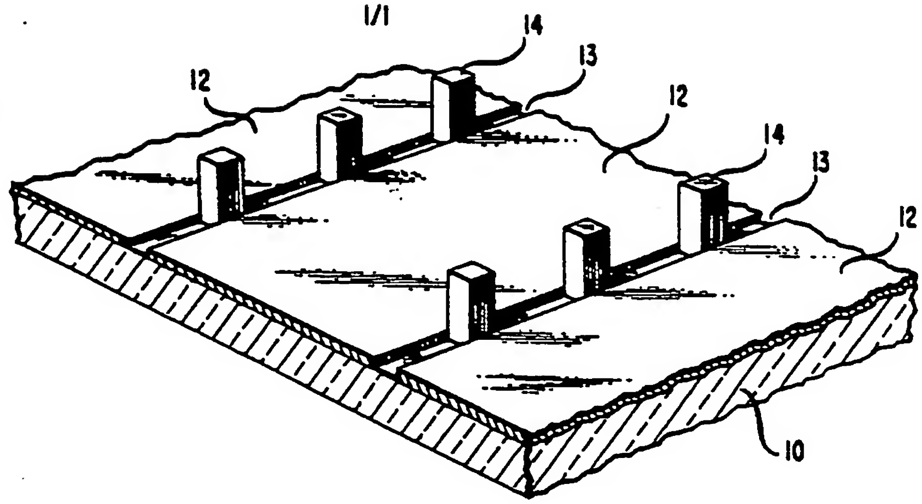


FIG. 2

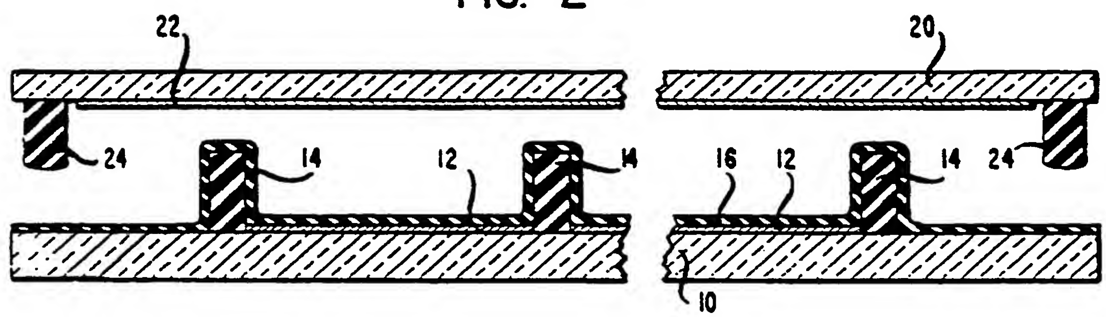
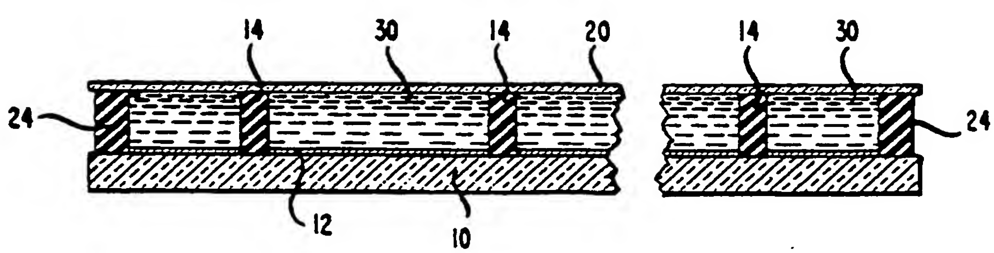


FIG. 3



INTERNATIONAL SEARCH REPORT

International Application No PCT/US 86/00338

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 02 F 1/133

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
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Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
P,Y Y A	Patents Abstracts of Japan, volume 9, no. 68 (P-344)(1791), 28 March 1985 & JP, A, 59201021 (CANON K.K.) 14 November 1984 --	1-4,6,7 10,11,13
Y A	Patents Abstracts of Japan, volume 6, no. 82 (P-116)(960), 20 May 1982 & JP, A, 5717923 (MATSUSHITA) 29 January 1982, see abstract --	1,3,6 11
Y	US, A, 4130408 (W.A. CROSSLAND et al.) 19 December 1978, see column 1, lines 35-38; figures 1,2 --	1,3
A	EP, A1, 0039871 (SOCIETE INDUSTRIELLE DES NOUVELLES TECHNIQUES) 18 November 1981, see page 3, lines 3-8; page 7, line 31 - page 9, line 6; figures 3-4 --	1,3,7,8,11
A	GB, A, 2102977 (B.B.C.) 9 February 1983	
P,Y,L	DE, A1, 3502160 (CANON K.K.) 25 July 1985, see claims 15,21,23,25,27; page 26,	./.

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
3rd June 1986	09 JUI 1986
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

International Application No. PCT/US 86/00338

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	line 29 - page 27, line 6; page 32, line 33 - page 33, line 5; figure 4 --	1-13
P,A, L	FR, A, 2561005 (CANON K.K.) 13 September 1985, see page 9, lines 14-19; page 14, line 14 - page 16, line 26; page 17, lines 30-35; page 20, lines 2-13; figures 3A-3C	1-13

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